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Large-Scale Aerosol Modeling and Analysis

Douglas L. Westphal
Naval Research Laboratory
7 Grace Hopper Ave, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4743   fax: (408) 656-4769   email: westphal@nrlmry.navy.mil

Cynthia A. Curtis
Naval Research Laboratory
7 Grace Hopper Ave, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4022   fax: (831) 656-4769   email: curtis@nrlmry.navy.mil

Annette L. Walker
Naval Research Laboratory
7 Grace Hopper Ave, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4722   fax: (831) 656-4769   email: walker@nrlmry.navy.mil

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LONG-TERM GOALS

The long-term goal of this research is to develop a practical predictive capability for visibility and weather effects of aerosol particles for the entire globe for timely use in planning and executing DoD operations and activities. The fundamental predicted variables are the concentrations of atmospheric aerosol particles responsible for degradation of Electro-Optical (EO) propagation in regions of DoD interest. Post-processors calculate the optical parameters useful in strategic and tactical planning, training, and operational activities. This forecast and simulation capability is also used in theoretical studies of the Earth's atmosphere and has operational usefulness in scientific field campaigns.

OBJECTIVES

The objective of this program is to investigate, develop, and test aerosol initialization, source, and prediction schemes. New knowledge and methodologies will be incorporated into an aerosol data assimilation and prediction system based on observations, aerosol process models, meteorological models, and their error characteristics.

APPROACH

The approach to the problem of aerosol and EO extinction prediction follows the approach used in numerical weather prediction, namely real-time assessment for initialization of first-principles models.

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The Naval Research Laboratory has developed a new capability for forecasting the global and regional concentration of atmospheric particulate matter and the subsequent effects on visibility. The regional model (COAMPS®[1]/Aerosol, with the aerosol software embedded in-line with the atmospheric model) became operational during Operation Iraqi Freedom (OIF). The separate and more independent global model, the Navy Aerosol Analysis and Prediction System (NAAPS), became operational in October 2005 and is executed after the Navy Operational Global Atmospheric Prediction System (NOGAPS), rather than as an integral part of it. Nonetheless, regardless of the technical approach, together these models predict the concentration of the dominant visibility-reducing aerosol species up to six days in advance anywhere on the globe. NAAPS and COAMPS are particularly useful for forecasts of dust storms in areas downwind of the large deserts of the world: Arabian Gulf, Sea of Japan, China Sea, Mediterranean Sea, and the Tropical Atlantic Ocean. NAAPS also accurately predicts the fate of large-scale smoke and pollution plumes. With its global and continuous coverage, NAAPS is invaluable in filling the gaps in observations of aerosol particles and visibility, which are largely provided from polar-orbiting satellites, and extends our understanding of aerosol particles and their impact on Navy operations. However, validation studies indicate that the forecasts would benefit from increasing the resolution and the number of species and the implementation of aerosol data assimilation.

WORK COMPLETED

The NRL high-resolution dust source database (DSD) is being adapted for use in defining dust source regions in NAAPS. The DSD has been crucial for high-resolution dust forecasting in SW Asia using COAMPS (Walker et al., 2009). Dust sources across East Asia have also been identified, using the same approach and are currently being beta-tested in COAMPS. Identification and entry of dust sources across Africa is presently under way. Once the African sources are complete the database will be utilized in NAAPS.

In 2009, NAAPS was improved by the addition of an aerosol data assimilation capability. The operational NRL Atmospheric Variational Data Assimilation System (NAVDAS) assimilates over-ocean MODIS Aerosol Optical Depths (NAVDAS-AOD; Zhang et al., 2008) and is the only operational global aerosol data assimilation system in the world. This year, an over-land product was evaluated and found to have positive impact on NAAPS forecasts (Figure 1.) With the over-ocean system, we have produced a ten-year reanalysis of global aerosol distribution which is being used by NRL and collaborators in various studies.

A model intercomparison and quantitative validation of aerosol forecast models has been initiated to satisfy the interest and needs of the warfighter, forecaster, CNMOC, and developers. Model forecasts from AFWA and UKMO are collected daily at NRL. The model comparison is done qualitatively by displaying the surface visibility forecasts side-by-side (Figure 2.) These are distributed to the warfighter via NIPRNET and SIRPNET.

NRL organized the International Cooperative for Aerosol Prediction (ICAP) and hosted two workshops on observability and verification in 2010. The major operational centers met to formulate a consensus viewpoint on the quality and availability of observations for initialization and validation of operational aerosol forecasting. As a result, the forecasts in digital format are being collected for quantitative validation with AERONET aerosol optical depth data and validation with surface reports of visibility. The AERONET are very accurate and provide the best validation, but the sparseness of

[1] COAMPS® is a registered trademark of the Naval Research Laboratory.

the network requires spatial and temporal averaging that precludes verification of event forecasting. The visibility reports are more numerous and report throughout the day, allowing real-time verification of events. The surface observation datasets have been screened for consistency and robustness. A select set of 3000 stations have been chosen for the visibility validation. Validation software has been developed.

RESULTS

To date, the modeling objective for NAAPS has been to provide the best aerosol distributions for EO propagation, especially in support of the Target Acquisition Weapons Software (TAWS) used for strike warfare by the tri-service DOD agencies. The applicability of NAAPS to the needs of the National System for Geospatial Intelligence (NSG) has been recognized by the Meteorological and Environmental Pathways to and from the Intelligence Community (MEPIC) and has resulted in their acceptance of NAAPS as the baseline source of aerosol parameters for their applications, namely scene correction. The standard NAAPS and Forecast of Aerosol Radiative Optical Properties (FAROP) output fields will satisfy their requirements with little change. However, funding from NRO has not yet been obtained.

Our plans to embed NAAPS inside NOGAPS have been put on hold pending the outcome of the decision on the potential use of the United Kingdom Meteorological Office (UKMO) Unified Model (UM) by NRL and FNMOC as a replacement for NOGAPS. An in-line model would allow better coupling to the dynamical forcing and would enable research on direct, semi-direct, and indirect forcing on numerical weather prediction (NWP), which are some of the major uncertainties in climate research. The UKMO has several aerosol models, two of which are in-line. These are called CLASSIC (similar to NAAPS) and UKCA (more detailed chemistry). CLASSIC is used by the Hadley Centre for climate runs and is used regionally. UKCA is practical only for climate runs. In the event of the adoption of the UM, NRL would evaluate, modify, and optimize CLASSIC or UKCA to meet Navy needs by focusing on the species important to EO propagation.

IMPACT/APPLICATIONS

NAAPS helps to satisfy the Navy's long-term goal of a predictive capability for aerosol particles and EO propagation. The forecasts of aerosol concentration are distributed via NIPRNET and SIPRNET for use by DoD forecasters, operators, planners, and aviators (http://www.nrlmry.navy.mil/aerosol/). The model output is processed by FNMOC and converted into the fundamental optical properties required to calculate EO propagation. These properties are used to populate the Tactical Environmental Data Server (TEDS) and subsequently used by TAWS to calculate slant-path visibility. The aerosol forecasts also are used to correct satellite retrievals of sea surface temperature (SST) by the Naval Oceanographic Office, thus improving tropical forecasts.

NAAPS also provides tools for the 6.1 and 6.2 aerosol research communities and the academic community. NAAPS data continues to be used in interactions with the research community appearing in peer-reviewed and conference papers. Over the year, collaborations have occurred between NRL and the Florida State University, Washington University (St. Louis), Washington State University, State of Vermont, University of Valladolid (Spain), University of California at San Diego, University of Helsinki, Scripps Institute of Oceanography, the University of Warsaw, Colorado State University, USGS and others. NAAPS forecasts enhance NRL's continued participation in field programs and will give us further opportunities for collaboration and access to important validation data.

The work done in this project satisfies some of the capability gaps and action items identified during the 2009 Senior METOC Officer (SMO) Conference of the Central Command (CENTCOM), the 2009 Dust, Smoke, and Aerosol (DSA) Forecasting Workshop, and the 2009 Weather Impact Decision Aids Conference. These include development of a tri-service dust source database, developing criteria and methodology for forecast validation, improvement to training, KML versions of products, and development of a roadmap for future improvements.

TRANSITIONS

NAAPS has been operational at FNMOC since October 2005. Improvements to NAAPS (as developed in this work unit) are transitioned to FNMOC via 6.4 funding provided by PMW-120. Initial transition of NAVDAS-AOD to 6.4 and FNMOC occurred in FY08. NAVDAS-AOD became operational at FNMOC on September 30, 2009.

RELATED PROJECTS

ONR 6.2 "Application of Earth Sciences Products" supports improvements in NAAPS physics and model initialization. The implementation of NAAPS, NAVDAS-AOD, FLAMBE and FAROP at FNMOC are supported by 6.4 funding from PMW-120 for "Large-scale Atmospheric Models", "Small-scale Atmospheric Models", and "Satellite Aerosol Data Assimilation." This funding also supports development and generation of products for use by the fleet. The NRL 6.1 Accelerated Research Initiative "Physics of Cloud Variability" uses NAAPS data and products for initialization, investigations and validation, as does the NRL 6.2 base project "Atmospheric Correction for Oceanography." NAAPS forecasts and simulations are used for several other applications: FAA Volcanic plumes, NASA "Vertical Dust Distribution Analysis and Lidar Data Assimilation", NASA Biomass-cloud interactions, scene correction, and ocean color and SST correction.

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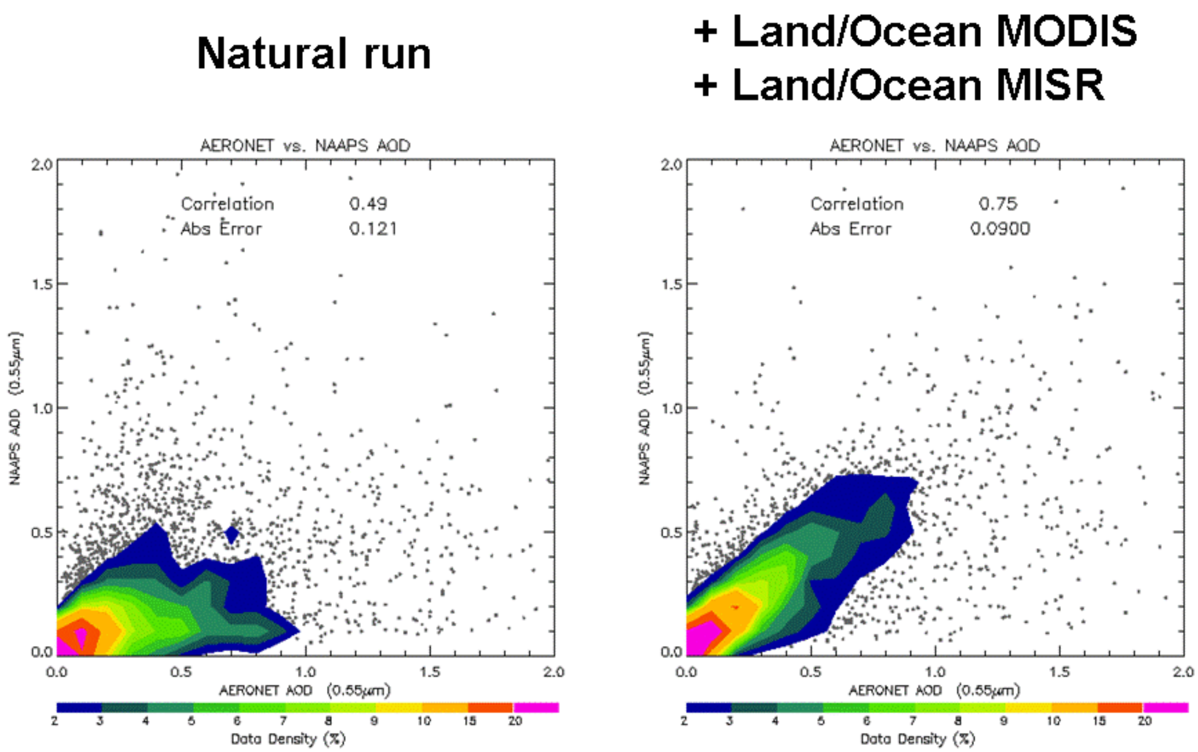

Figure 1. Comparison of NAAPS analysis of aerosol optical depth (AOD) vs. AERONET AOD. (left) NAAPS without data assimilation. The correlation is 0.49. (Right) NAAPS with data assimilation of over-ocean and over-land AOD from MODIS and MISR sensors. The correlation increases to 0.75.

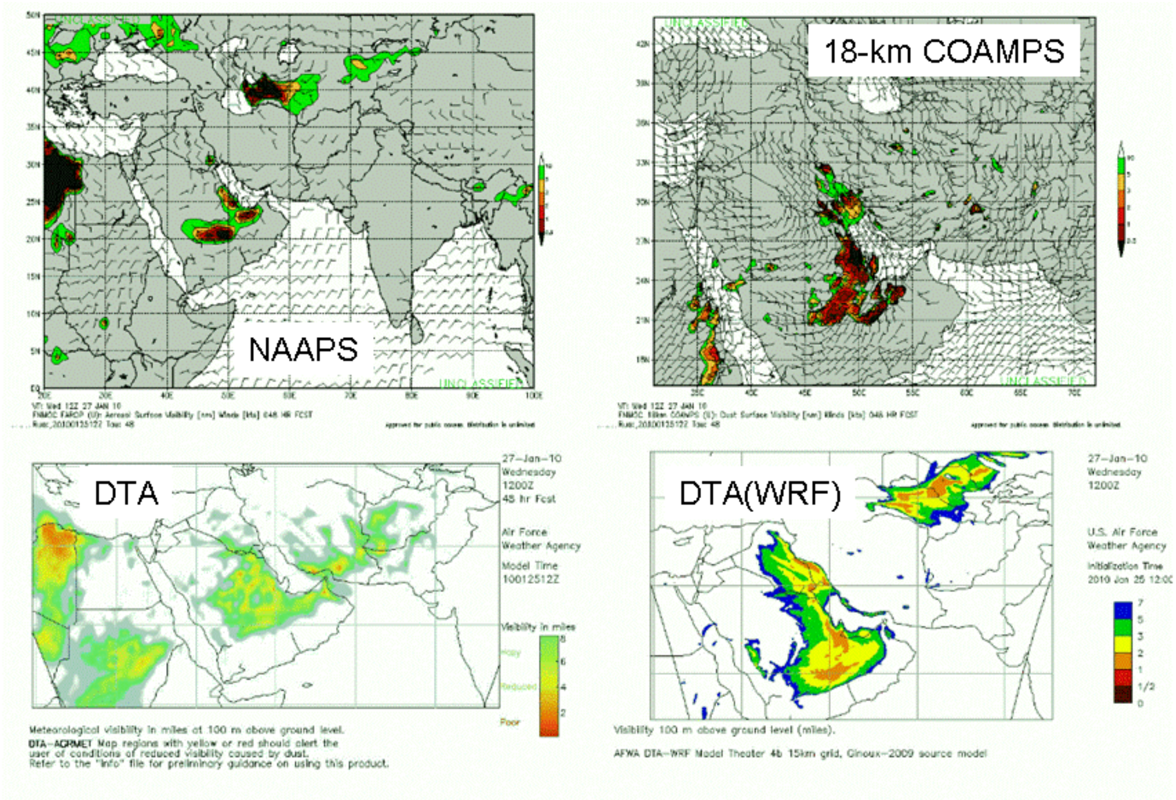

Figure 2. Four-panel product used to compare multiple model forecasts of visibility in SW Asia dust storms. On the web the product is available for a five day forecast at a frequency of 6 hours. (upper-left) NAAPS; (upper-right) COAMPS; (lower-left) Dust Transport Application (DTA); and (lower-right) DTA(WRF). All models show varied depictions of a dust storm originating in southern Iraq, Kuwait, Saudi Arabia and Libya.